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This document describes the theory and mode of operation to be used with a cathode ray oscilloscope. Safety percautions to be taken, methods of calibration, and uses of the equipment in school operation are given. A brief "trouble-shooting" section and a bibliography of other reference is included. (GR)

NATIONAL SCIENCE TEACHERS ASSOCIATION

how to

USE AN OSCILLOSCOPE

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INTRODUCTION

The cathode ray oscilloscope has come to be one of the most widely used electronic instruments. Its major use was originally in the field of electricity and electronics, but as electronic instrumentation became more widely used, the oscilloscope became important in a great variety of instances, and its usefulness continues to grow. Today the oscilloscope is found in hospitals, monitoring the heartbeats of patients suffering from cardiac difficulties; it is found in automobile repair shops, monitoring the duration and intensity of the spark plug discharge and also the pressure variations in the cylinder; it is used in research laboratories as one of the read-out devices of an analog computer; it is used as a display device in some computer-assisted instruction devices, and in this instance the student viewing the screen can reply by using a light pencil to write on the oscilloscope screen. It is used in many engineering fields, in various branches of medicine, and in many other fields where transient or repetitive phenomena occur. It is, of course, found in almost every home as the television viewing screen.

An oscilloscope is an electrical test instrument used to view electrical oscillations on a fluorescent screen. It can also be used to view mechanical and acoustical oscillations if they are first converted into electrical voltages. In this sense, the oscilloscope is a *display device* used for the visual representation of external phenomena.

The oscilloscope is also an electrical measuring device. It can be used as a voltmeter (usually A.C.) and in fact has some advantages over the usual A.C. voltmeter when non-sinusoidal waves are to be measured or when a wide range of frequencies is to be measured, such as in high fidelity amplifiers. It can also be used to measure short time intervals and, therefore, can be used as a distance-measuring device as in radar, or as a timing device.

The oscilloscope, being an electronic instrument, can itself be used as an instructional device. Its own circuits can be used for demonstrations, or the circuit outputs can be displayed.

Figure 1 shows a block diagram of a general-purpose oscilloscope. Reference to this diagram will aid in understanding the descriptions of the various oscilloscope circuits and of the functions of the controls and terminals.

CATHODE RAY TUBE

An oscilloscope has many similarities to a television set, and both show pictures on a fluorescent screen. The television screen shows pictures which have been transmitted from the studio. The oscilloscope screen shows electrical waveforms which come from electrical circuits or have been derived from other energy transformations and have been changed to electrical waveforms by means of transducers. Some common transducers are phonograph pick-ups, microphones, and photoelectric cells.

The fluorescent screen is deposited on the face of a special tube called a cathode ray tube (CRT). The cathode ray tube is essentially an inertia-less voltmeter or ammeter, sensitive to phase and capable of indication in two independent planes. The indication is by means of an electron beam impinging on the fluorescent screen. The beam is capable of deflection at high rates of speed by the action of either electric or magnetic fields. The energy required for deflection is extremely small as compared with that required for other indicating devices.

The cathode ray tube (see Figure 2) consists of seven essential components contained within a highly evacuated glass envelope, namely:

1. A source of electrons, usually a hot cathode

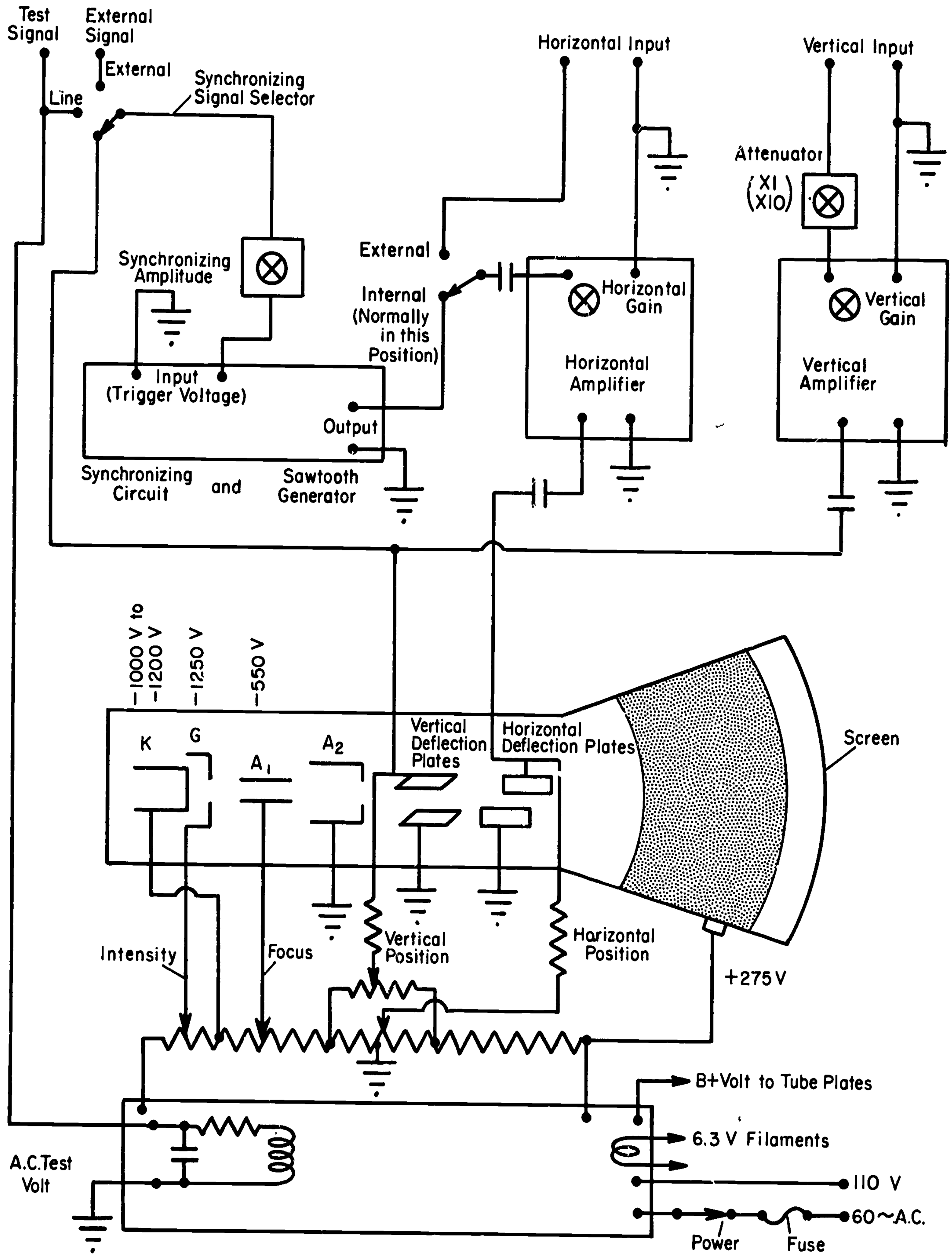

Figure 1 Cathode Ray Oscilloscope (one possible type)
Block Diagram

2. A grid to control the intensity of the electron beam
3. A first anode to draw the electrons from the cathode into the beam
4. A focusing anode
5. A second anode to accelerate the electrons
6. Electrodes to deflect the beam by means of the voltage to be observed
7. A fluorescent screen upon which the electrons impinge

When the tube is in operation, the electrons impinge on the screen. The resultant fluorescent spot indicates the position or immediate past position of the beam terminus, depending upon the decay characteristics of the phosphor of the screen. This may be a matter of minutes, seconds, or microseconds. An easy way to picture this luminous spot would be to compare it to the spot of light made by the beam from a flashlight shining on a wall. By moving the lighted flashlight horizontally and vertically, different wave patterns could be traced on the wall. If exactly the same motion could be produced over and over again and very rapidly, the wall would seem to have the waveform painted on it with light, because of the persistence of vision. The line or waveform on a cathode ray tube stays visible, that is, its image is retained by the eye, in much the same manner.

Another way to think of this luminous spot is to imagine oneself standing on the shore of a lake, on a windless night when the water is absolutely still, watching a green light on a boat that is moving across the lake. The horizontal motion of the light is analogous to the oscilloscope trace. If a wind develops so that waves appear on the water, the boat (and the light) will move up and down as it moves across the lake. The pattern traced out by the light is analogous to the effect produced on an oscilloscope screen when a sine wave is fed into the oscilloscope. (A sine wave is a graphical representation of a simple harmonic motion.)

Beam Deflection

The electron beam after passing through the second anode passes through the electric field set up between the deflection plates. (See Figure 2.) The beam may be deflected electrostatically by applying a voltage to the deflecting plates. The vertical deflection system causes the beam to be moved up or down, and the horizontal deflection system causes the beam to be moved left or right. The plates are mounted in pairs at right angles to each other and parallel to the beam. If one plate is made positive and the other negative, the electron beam will be bent away from the negative plate toward the positive plate.

The bending action of the deflection plates on the electron beam can be compared to the motion of a negatively charged pith

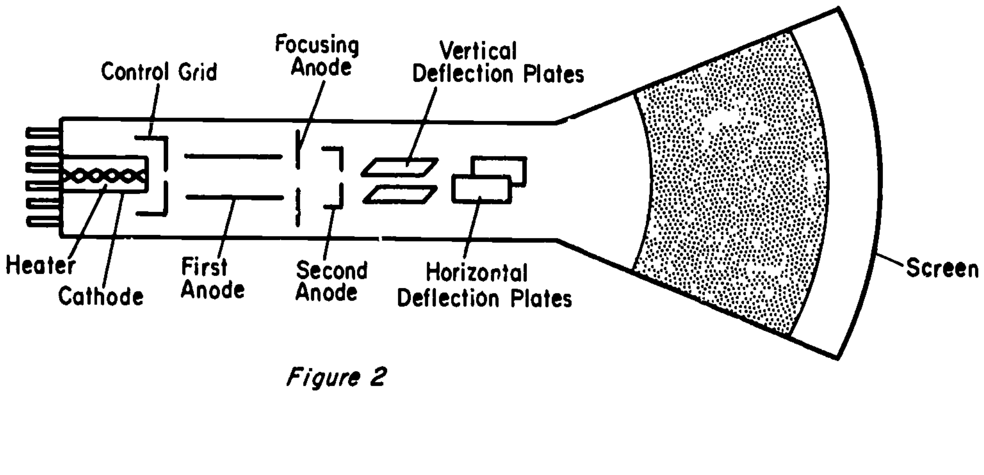

Figure 2

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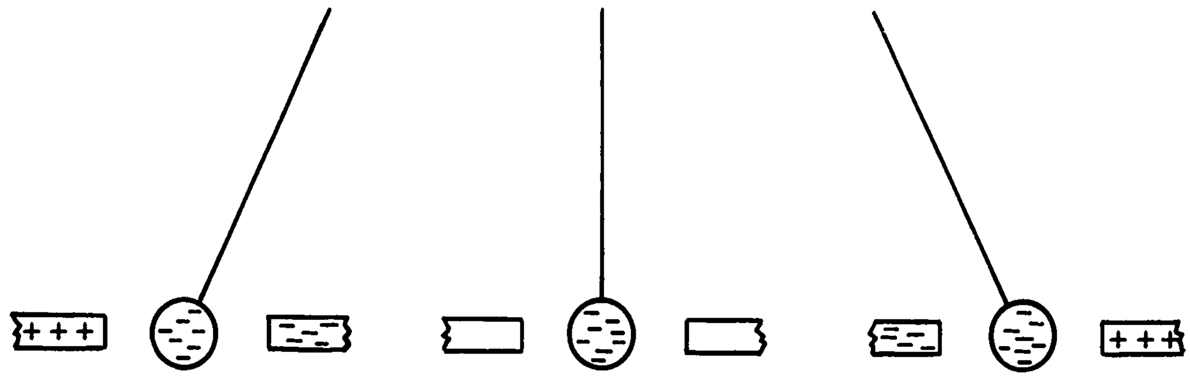


Figure 3

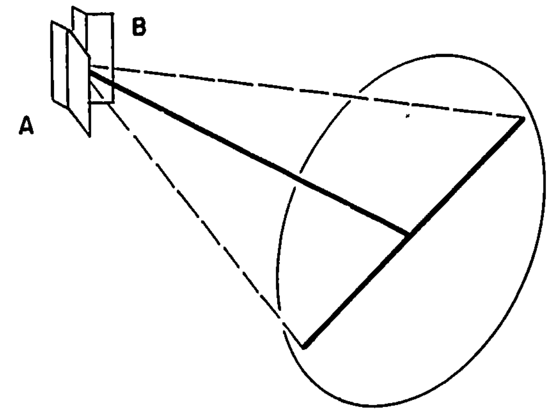


Figure 4b

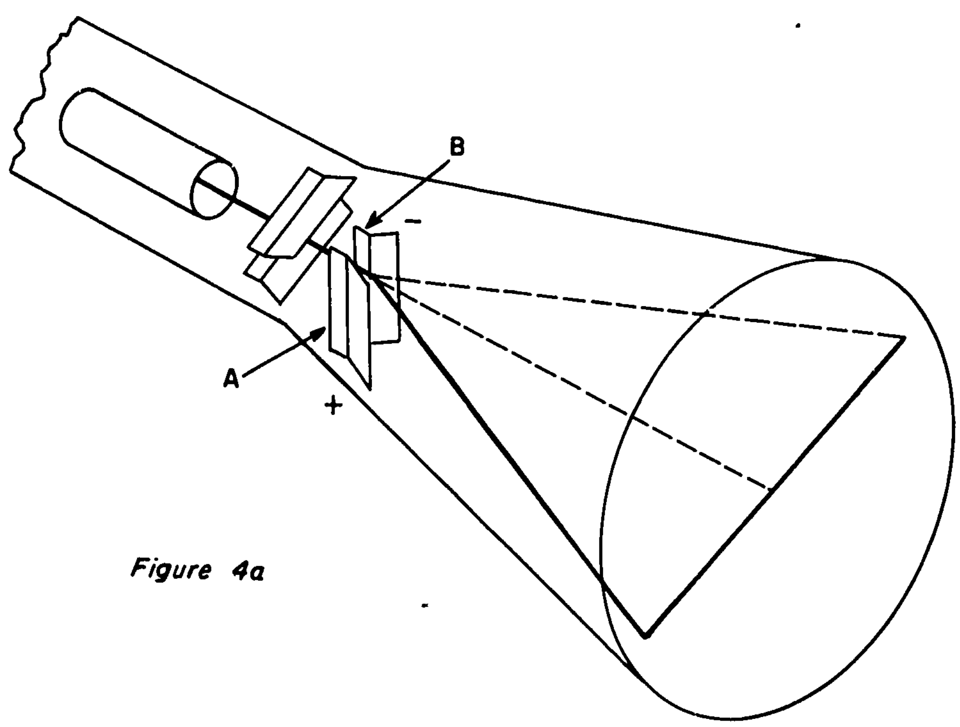


Figure 4a

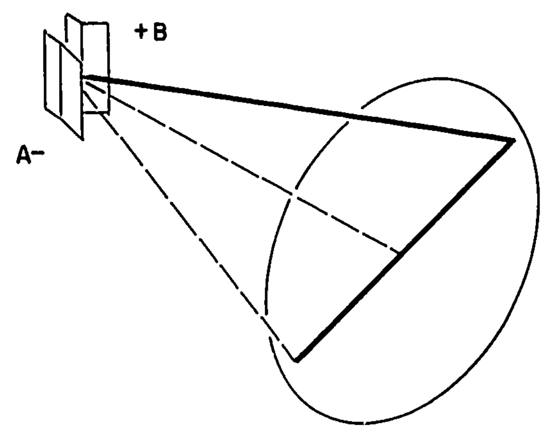


Figure 4c

ball as it moves under the influence of two nearby charged bodies as shown in Figure 3.

Figure 4 shows the effects of different voltages applied to the horizontal deflection plates. In 4a, plate A is positive with respect to plate B. In 4b, plate A is the same as plate B, and in 4c, plate A is negative with respect to plate B.

As the voltage on plate A is gradually changed from positive to negative, a horizontal line will be traced on the screen. Similarly, the vertical deflection plates can make the electron beam go up and down.

The speed with which the spot of light moves across the screen will be governed by the rate and manner in which the deflection plate voltages are changing. If the plates are the horizontal plates of the CRT, and a special A.C. voltage that varies linearly with time is applied to these plates, the spot moving across the screen will trace out equal distances in equal times, and the horizontal trace on the CRT screen is said to be linear. Such an A.C. voltage is called a sawtooth waveform. Figure 5 shows a typical sawtooth waveform (5a) and the resulting trace on the screen (5b).

The section from A to B will move the spot from left to right across the screen. The section from B to C will move the spot back from right to left. Since it is usual to display graphic information from left to right, it is desirable to display waveforms only on this part of the swing and not when it returns from right to left. Therefore, the retrace time from right to left is made as short as possible. In addition, the retrace is often made invisible by a procedure called blanking. In this

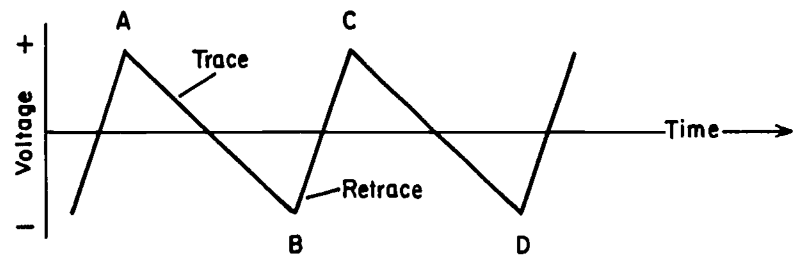


Figure 5a
Typical Sawtooth Waveform

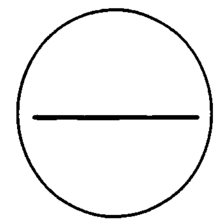


Figure 5b
Picture on Scope Face

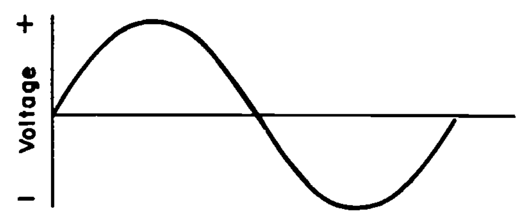


Figure 6a
Typical Sine Waveform

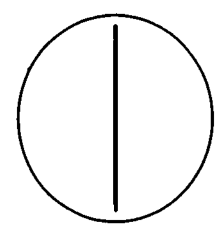


Figure 6b
Picture on Scope Face

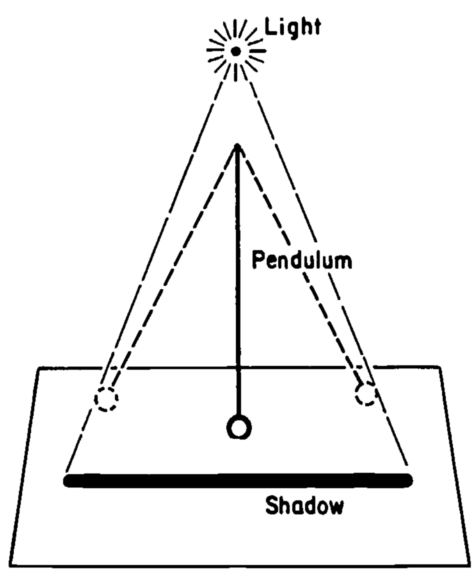


Figure 7

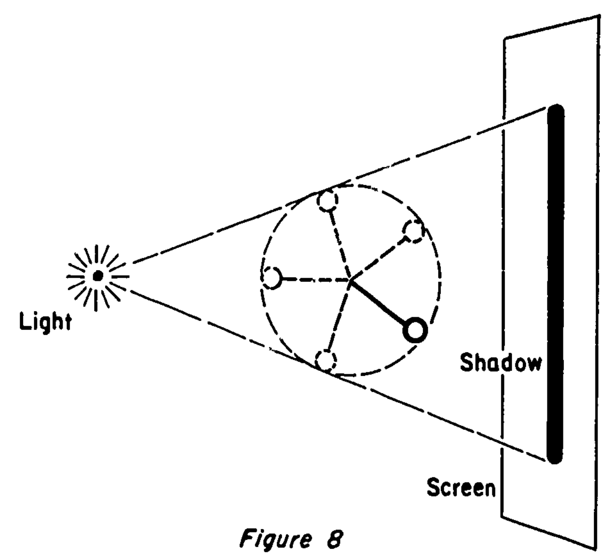


Figure 8

procedure the trace is blanked out by making the beam intensity so low during the retrace time that it becomes invisible on the screen.

Figure 6 shows a sine wave voltage (6a) applied to the vertical deflection plates and the resulting trace on the screen (6b).

In this case a vertical line is traced out but it *does not* move up and down at an even rate. The trace in this case is the result of the simple harmonic motion of the spot and can be likened to the shadow produced by the bob of a vibrating pendulum (Figure 7) or the vertical displacements of a particle moving in a circular path as it goes through one complete revolution. (See Figure 8.)

Each waveform—sawtooth or sine—when applied separately, results in a straight line. If, however, they are applied simultaneously, a waveform is traced out on the screen as shown in Figure 9. Dotted lines connect corresponding points of the applied waveforms.

If the frequency of the applied sine wave is twice that of the sawtooth wave, two sine waves will appear on the screen (Figure 10a). If the sawtooth is twice the frequency of the sine wave, only one-half the sine wave will appear (Figure 10b). If the waveform applied to the vertical deflection plates is other than a sine wave, the spot will trace out a replica of the applied wave as shown in Figures 10c to 10f.

It is possible that the signals to be applied to the deflection plates might be of too low a value to produce sufficient deflection on the screen. Therefore, amplifiers are incorporated in most oscilloscopes to amplify the input voltage so as to provide sufficient deflection. Usually these amplifiers have a frequency range from a few Hz* to ap-

* 1 Hertz (Hz) = one cycle per second.
1 Mega Hertz (MHz) = one million cycles per second.

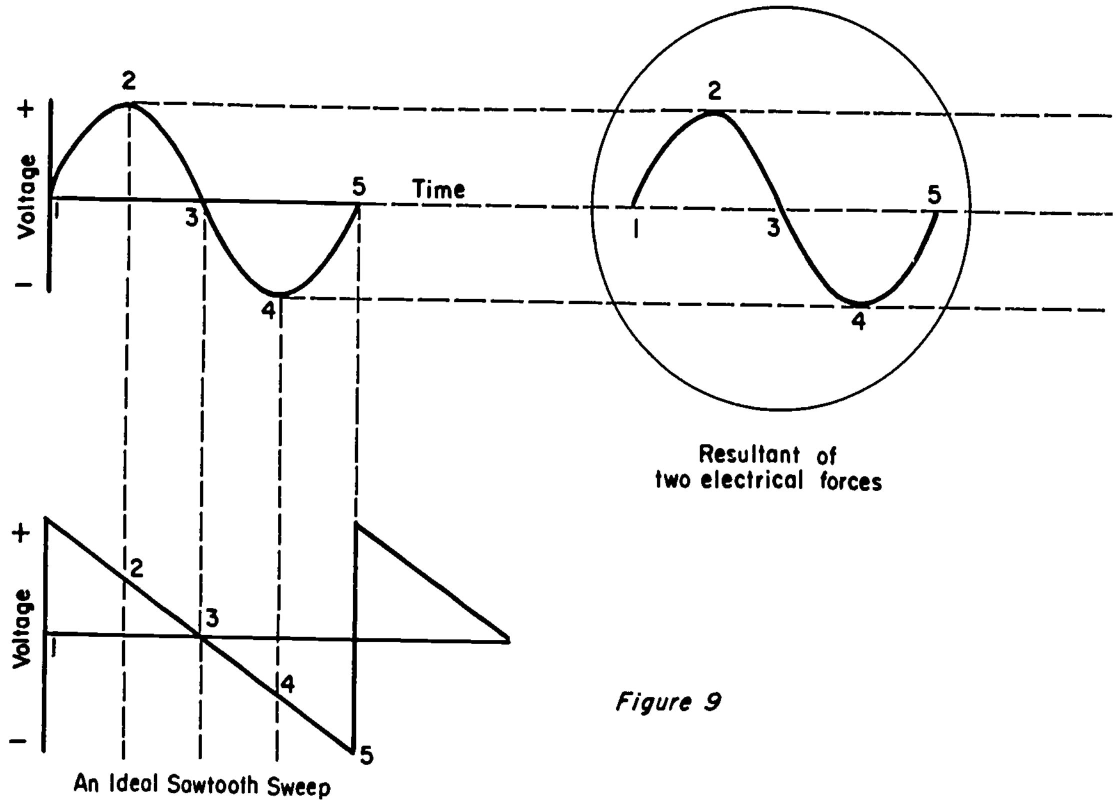


Figure 9

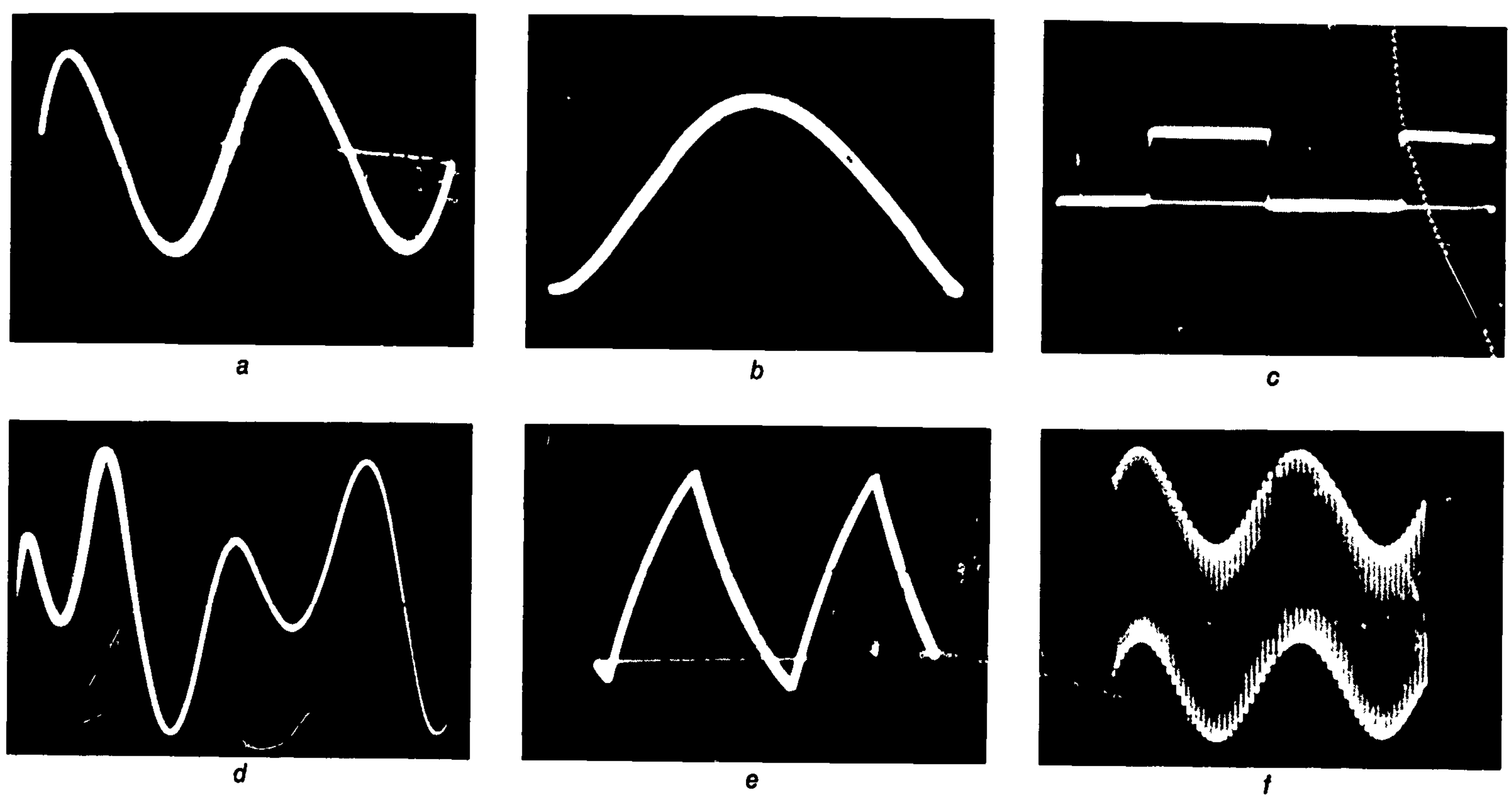


Figure 10 (a-f). These heavy line pictures were made purposely by using a high intensity trace so a more striking photograph could be obtained.

proximately 1 Mega Hz (MHz). Only in special application equipment is this range extended over 5 MHz. Thus voltage waveforms with appreciable frequency content above 1 MHz cannot be fed into the average oscilloscope amplifier without undue distortion of the amplified waveform.

In order to observe waveforms with frequency content greater than the band width of the oscilloscope amplifier, it is necessary to inject these voltages directly to the deflection plates. (See the instruction book for your oscilloscope.)

FRONT PANEL CONTROLS

In order to be able to use an oscilloscope effectively, one must not only understand its theory, but spend a certain amount of "hands-on" time becoming acquainted with the elements of the device. The instruction manual that comes with your scope should be used along with the general descriptions given here. Many schools have oscilloscopes which have been received from military surplus and are without instruction manuals. Some schools have instruments for which the in-

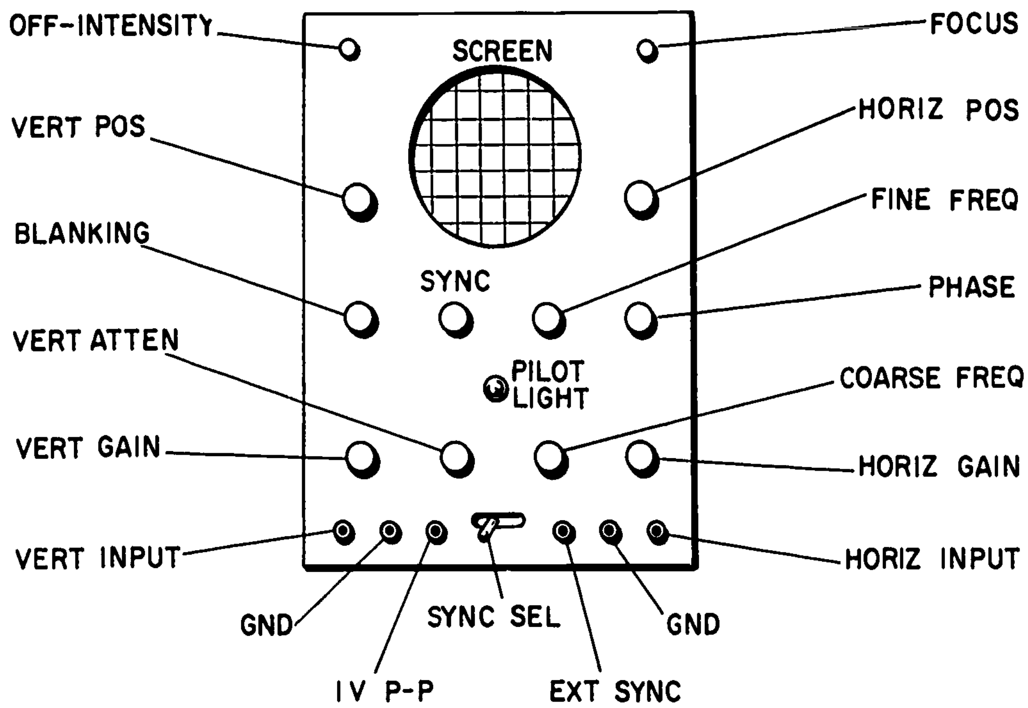


Figure 11

struction book has been lost or is inadequate for school use. The theory of operation, experiments, and references given here should enable one to use effectively almost any oscilloscope. Familiarity with the functions of each control and segment of the device has the added advantage of helping one to pinpoint a malfunction or failure in use.

Figure 11 shows the front panel of a typical oscilloscope. (Figure 1 relates these controls to the internal circuit.) Your own oscilloscope may be different from this model. If it is different, establish the location of each of the controls. Some oscilloscopes do not have all of these controls, and some may have additional controls.

OFF-INTENSITY—Applies power to the instrument and increases intensity of the trace on the screen of the CRT when control is turned clockwise from OFF position.

FOCUS—Adjusts the sharpness of the trace. Normally requires adjustment when setting of the INTENSITY control is changed.

VERTical POSition—Adjusts vertical position of trace (often called the vertical centering control).

HORIZontal POSition—Adjusts horizontal position of trace (also called the horizontal centering control).

VERTical ATTENuator (or vertical input sensitivity or range)—Provides a coarse adjustment for the vertical size of any wave form that appears on the screen. This switch is usually left on the X1 position, but it may be turned to X10 or X100 for higher voltages.

VERTical GAIN—Controls fine adjustment of the vertical size of any waveform that appears on the screen.

COARSE FREQuency (also horizontal frequency or sweep)—Selects the frequency range of the sweep oscillator. Used in conjunction with the FINE FREQ (or sweep vernier) control. Most oscilloscopes also make external sweep or line sweep connections through this switch.

FINE FREQuency (also sweep vernier)—Provides continuous control of the oscillator sweep frequency over the range selected by the COARSE FREQ control. Also provides overlap of the coarse frequency control positions. This control is usually inoperative when the COARSE FREQ control is in EXTernal or LINE position.

HORIZontal GAIN—Adjusts the width of the waveform that appears on the screen.

SYNChronization SELector—Selects synchronizing voltages for the sweep oscillator. This is normally internally connected with provisions for external connection. Some oscilloscopes have additional positions such as LINE or + or −.

SYNChronization—The synchronizing adjustment—controls the amplitude and polarity of the synchronizing voltage applied to the grid of the sweep oscillator. Some oscilloscopes have a single direction control with the polarity selected by the SYNC SEL switch. **Important:** This control should be adjusted to the minimum setting necessary to lock the waveform in a stationary position. Synchronization circuits are used to hold the fre-

quency of the horizontal sweep oscillator to the exact frequency of the input waveform. This causes the trace of the CRT to start at exactly the same point on the input waveform each time it sweeps across the screen, thereby making the waveform appear stationary on the screen.

PHASE—Controls the phase of the sinusoidal sweep when a 60 Hz sine wave or line sweep is used. A phase control *will not* be found on every oscilloscope.

BLANKING—See explanation on pages 4-5.

VERTical INPUT—Feeds the input signal to the vertical amplifier through the attenuator circuits.

1v P-P or TEST SIGNAL—Brings a 60 Hz sine wave test signal to the front panel from the low-voltage power supply. This signal is generally used in calibrating the oscilloscope for use as a peak reading voltmeter. On some oscilloscopes this voltage is applied internally by means of a calibrating switch. (See **Calibration and Voltage Measurement,** page 10.)

EXTernal SYNChronization—An external synchronizing signal should be connected between this terminal and the ground terminal. The SYNC SEL switch should be set to EXT.

HORIZontal INPUT—An external signal for the horizontal amplifier (sweep amplifier) should be connected between this terminal and the ground terminal. The COARSE FREQ control should be set to EXT.

GROUND (GND)—Connected directly to case and chassis.

SAFETY PRECAUTIONS

The metal case of an oscilloscope is connected to the ground of the internal circuit. For proper operation the ground terminal of the instrument should always be connected to the ground of the associated equipment being used or tested. *Always make this connection first.*

When working with electrical and electronic equipment, one must remember that there is always the danger of hazardous voltages. The teacher *must* be familiar with the equipment being tested. The following precautions have been shown to be most important.

1. Remove power before connecting test leads to high-voltage points. When making connections with alligator clips or when positioning probes, it is best to *keep one hand in your pocket.* A rubber mat on the floor, or a properly insulated floor lessens the danger of shock.

2. Filter capacitors may store a charge large enough to be hazardous. Discharge filter capacitors before attaching test leads.

3. Check test leads for frayed or broken insulation before working with them.

OPERATION

The lead (connecting wire) which is connected between the oscilloscope and the signal source should be shielded. A shielded lead will not pick up any stray voltages which tend to distort the waveform. The lead is usually about 3 feet long and constructed as shown in Figure 12.

The lead may be made of phono or microphone cable or flexible coaxial cable such as is used in some TV antenna systems. Where high frequency losses must be minimized, a special low-capacitance probe and cable can be purchased from electronic supply sources.

Some oscilloscopes have terminals which accept banana plugs. Double banana plugs are available to terminate the lead wire, thereby making connections to the oscilloscope easier. Some oscilloscopes use a coaxial type of input. The center terminal of a coaxial input is the same as the vertical input. The outer shell of a coaxial input is ground.

To become familiar with the operation of the oscilloscope, follow the procedure outlined below, in the order given.

Initial Procedure

1. Connect the power cord to an A.C. outlet supplying 105-125 volts at 50-60 Hz. Set VERT GAIN and HORIZ GAIN controls in fully counterclockwise position. Disconnect lead from VERT INPUT connector.

2. Turn the INTENSITY control clockwise from the OFF position. Some scopes have a delayed pilot light action to indicate that the instrument has warmed up.

3. Rotate the INTENSITY control farther clockwise until either a line or a spot appears on the screen. Adjust positioning (centering) controls if necessary. The spot should increase in brilliance as the INTENSITY control is turned clockwise.

Note: Do not allow a small spot of high brilliance to remain stationary on the screen for an appreciable length of time because discoloration or burning of the screen may result.

4. Position the spot in the center of the screen by adjusting the VERT POS and HORIZ POS controls.

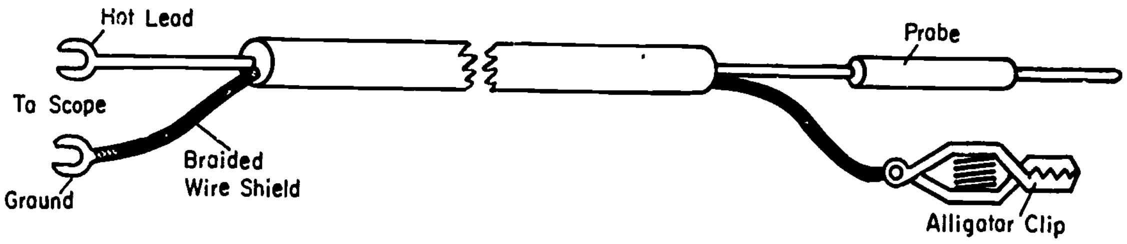


Figure 12

5. Adjust the FOCUS control for an image of maximum sharpness.

Vertical-Amplifier Operation

1. Connect one end of the input lead to the VERT INPUT connector, making sure that the shield is connected to the ground connector.

2. Connect the probe end of the input lead to the output of a bell transformer or train transformer as shown in Figure 13.

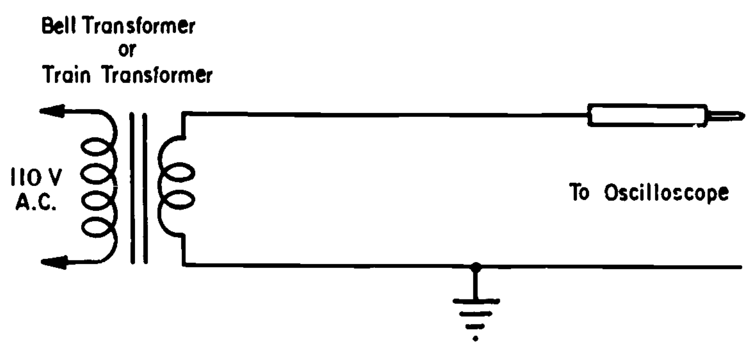


Figure 13

If a transformer is not available, a signal can be obtained by holding the probe end of the lead (also called the hot lead) between the thumb and forefinger. (The human body acts as a fairly good antenna.) A signal can also be obtained from the test signal connector if this is available on the scope. In this case, plug the hot lead into the test connector (1v P-P on the illustrated scope, Figure 11).

3. Turn the VERT GAIN control clockwise until the spot or line is expanded vertically to a height of about three inches. The VERT ATTEN (or V range) switch should be on the X1 position.

4. Set the SYNC SEL switch to the INT position. Set SYNC (or sync amplitude) control to the zero position. This is usually fully counterclockwise on most scopes. Set the COARSE FREQ switch to the 15-90 (or 10-100) position. Increase the HORIZ GAIN control until the pattern covers almost the complete width of the screen. Adjust the FINE FREQ (or sweep vernier) control so that the pattern is almost stationary, and one or two waves appear on the screen. Adjust the SYNC control to lock in the pattern. Turn VERT ATTEN to each of its settings and note change in height. Vary the VERT GAIN to see its effect on the pattern. By setting VERT ATTEN and adjusting VERT GAIN, any desired height of pattern can be obtained.

Horizontal-Amplifier Operation

1. Disconnect probe from the A.C. source used above. Turn COARSE FREQ selector switch to EXT. Connect test leads to HORIZ INPUT. (For this part, the test leads may be removed from the VERT INPUT and used.) Apply an A.C. signal of 1 to 10v to the HORIZ INPUT circuit, connecting the ground side to GND and the "hot" side to the HORIZ INPUT. (The A.C. voltage source used in the vertical-amplifier operation may be used.) A horizontal line will appear on the screen, indicating that an external signal has been applied to the horizontal deflection plates of the CRT. Turn the HORIZ GAIN control and note variation in line length.

2. Disconnect the lead from the voltage source. The horizontal line will be replaced by a spot. **Caution:** Do not let spot remain on screen. Phosphor may burn out!

3. Turn the COARSE FREQ selector switch to the LINE position. (On the scope in Figure 11 this is done by keeping the switch in EXT position and connecting the HORIZ INPUT to 1v P-P.) When the switch is set to LINE position, part of the power line signal is fed to the horizontal amplifier, providing a sinusoidal horizontal deflection voltage of power-line frequency.

4. Turn the COARSE FREQ control to the 15-90 position. Turn the SYNC SEL switch to INT. When these controls are set as indicated, the sawtooth output from the sweep oscillator is applied internally to the horizontal amplifier, and a linear horizontal trace appears on the screen.

Sweep-Oscillator Operation (normally used)

1. Connect the test leads to the VERT INPUT connector. Connect the probe and ground lead to

the low-voltage transformer output as in Figure 13. Turn the VERT ATTEN switch to the X1 position and adjust the VERT GAIN control until the pattern height is about two inches.

2. Set the COARSE FREQ (sweep) control to the 15-90 position. Turn the SYNC control to the zero position. Adjust the FINE FREQ (sweep vernier) for a single-cycle trace on the screen, drifting slowly leftward. Advance SYNC control just far enough to lock in the pattern. Readjust FINE FREQ and SYNC slightly if necessary to obtain solid lock in. **Note:** If too much synchronizing signal is applied, it will cause the sweep voltage to be distorted.

3. Turn FINE FREQ control slowly counterclockwise and note that the pattern will go out of synchronization. Continue turning FINE FREQ counterclockwise and note that the pattern will lock in with two cycles, then with three cycles, etc., up to four to six cycles depending upon the oscilloscope. In this example, when the FINE FREQ is set to produce two cycles, the horizontal sweep rate is 60/2 or 30 cycles. When FINE FREQ is set to produce three cycles, the horizontal sweep rate is 60/3 or 20 cycles, etc.

4. If an audio frequency (A.F.) signal generator is available, it is well to use the generator as an external signal source and repeat the experiment above at various frequencies. The use of the A.F. generator will be more fully described later. (See page 11.)

CALIBRATION AND VOLTAGE MEASUREMENT

Most oscilloscopes provide special facilities for simple and quick voltage calibration of the vertical amplifier and CRT screen. Most oscilloscopes have a graph screen or grid lines. When the scope has been calibrated, the grid lines can be used to measure the deflection amplitude of a displayed waveform directly in volts.

Calibration is accomplished as follows: For scopes with a built-in calibrating voltage, set the switch to CALIBRATION. For scopes with a test signal connector on the front panel, connect this test signal to the VERT INPUT by means of the probe and lead. For scopes with neither of the above, connect a source of undistorted sine waves to the VERT INPUT as in Figure 13. Connect an A.C. voltmeter to the vertical input of the oscilloscope. Most A.C. voltmeters read Root Mean Square (RMS) values. To determine the peak-to-peak value of this voltage, multiply the reading by 2.82. Turn the HORIZ GAIN to zero. (For this procedure it is easier to work with a simple vertical line, and this also results in greater accuracy.) Adjust the VERT GAIN so that the height of the trace is sufficient for the measurement to be made.

Example: It is desired to measure voltages in the range of 125v peak to peak. A 6.3 volt A.C. RMS source is available as a calibrating voltage. The CRT grid has eight (8) major (or 40 small) divisions on the vertical axis.

6.3v RMS (2.82) — 17.8v peak to peak

Connect calibrating source to VERT INPUT. Adjust VERT GAIN so that vertical trace covers one major division. **DO NOT, during this usage, touch the VERT GAIN control, or calibration will change.** Connect probe to signal source to be measured and determine voltage on the basis of one major division per 17.8v.

Obviously if an integral value, peak-to-peak calibrating voltage is available, as is the case with most scopes, the grid can be calibrated so that voltages can be read *simply* and *directly* from the screen.

USES OF THE OSCILLOSCOPE

Amplitude—Since sine waves are easily obtained on an oscilloscope, and their height is easily changed by use of the VERT GAIN control, the *amplitude* of a wave can be varied dynamically while frequency and wavelength remain constant.

Wavelength—The concept of wavelength is also well demonstrated on the scope. By manipulating the HORIZ GAIN control, the wavelength can be increased or decreased.

Frequency—While keeping the amplitude constant, the FINE FREQ control can be varied as in 3 under Sweep-Oscillator Operation. This will show the relation between frequency and wavelength for a given sweep frequency or spot velocity. The speed of the spot (sweep) is here analogous to the speed of a wave traveling in a medium. For example, if the sweep rate is 60 Hz and the wave frequency is also 60 Hz, one complete wave will appear. If the sweep rate is reduced to 30 Hz and the wave frequency maintained at 60 Hz, two complete waves will occur. The frequency is now seen to have doubled and wavelength decreased to one half. (HORIZ GAIN control must be kept constant during this demonstration.)

A very crude measurement of frequency can be obtained for any waveform displayed on the CRT. By manipulating the frequency controls until one cycle of the wave form appears on the screen, the frequency can be roughly determined by the settings of these controls.

Lissajous Figures—A more accurate method of frequency measurement makes use of an audio frequency (A.F.) generator and Lissajous figures.

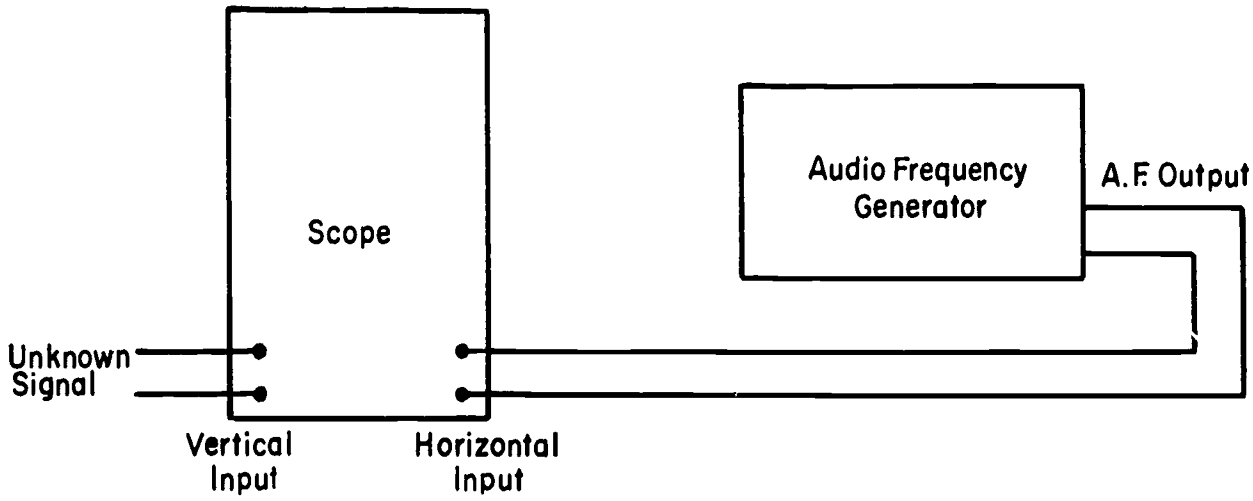


Figure 14

The setup for this method is shown in Figure 14.

The sine wave signal of unknown frequency is applied to the vertical input. The COARSE FREQ control is set to EXT and the sine wave output of an A.F. generator is connected to the horizontal input. The A.F. generator is used to apply a sine wave sweep to the horizontal deflection plates at a frequency determined by the setting of the A.F. generator. The amplitude of this sweep can be controlled by the A.F. output control or by the HORIZ GAIN control.

To measure the unknown frequency, adjust the frequency of the A.F. generator to obtain the circular pattern shown in Figure 15a. The VERT GAIN and HORIZ GAIN may have to be adjusted to obtain the pattern. The unknown frequency is then the same as the reading on the A.F. generator scale. The accuracy of the measurement depends upon the accuracy of the A.F. generator.

More complex Lissajous figures can be obtained by using vertical and horizontal frequencies that are in the ratio of small whole numbers. By using such figures the measurement range of the A.F. generator can be extended. See Figure 15b and 15c.

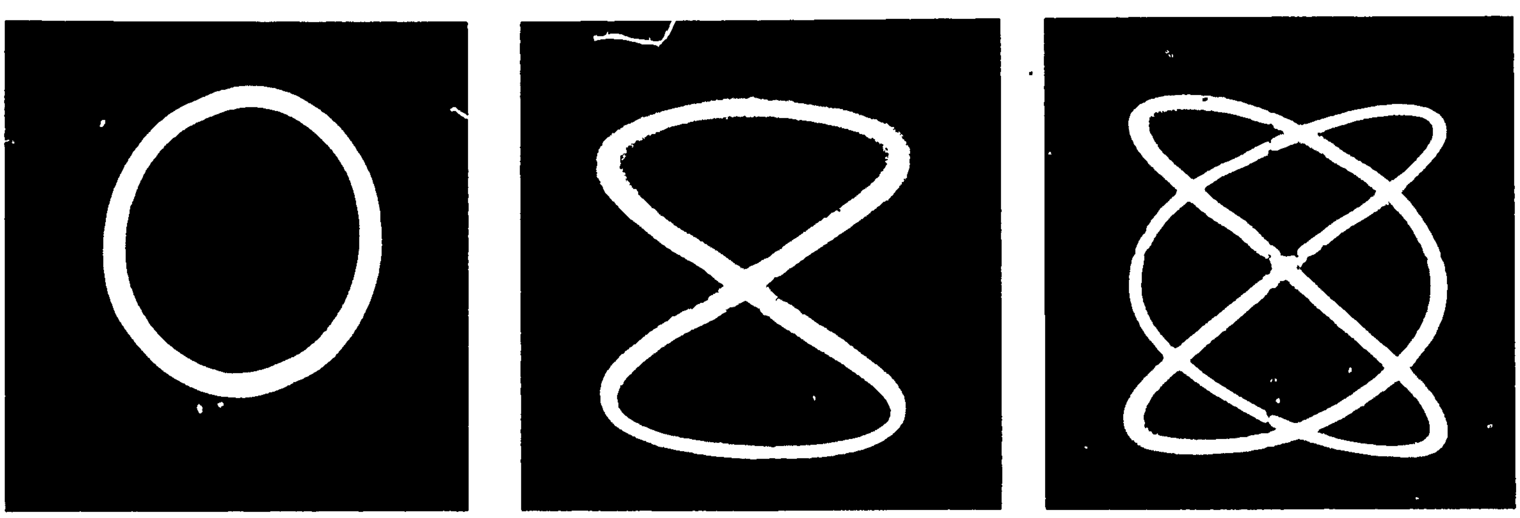
The scope test signal or line sweep can be used as a 60 Hz sine wave sweep, and the unknown signal frequency can be measured in terms of this sweep.

The unknown frequency fx is determined by the following equation:

$$fx = \frac{\text{number of loops horizontally}}{\text{number of loops vertically}} \times \text{horizontal frequency}$$

Phase—Phase or phase shift can also be measured with an oscilloscope.

Superposition—The waveform resulting from the addition of two simpler waveforms can be shown by using the normal sawtooth sweep, at the correct frequency, and feeding two sine wave signals into the VERT INPUT. The two input signals can be obtained from two A.F. generators in parallel



a b c

Figure 15 (a-c). Lissajous figures. These heavy line pictures were made purposely by using a high intensity trace so a more striking photograph could be obtained.

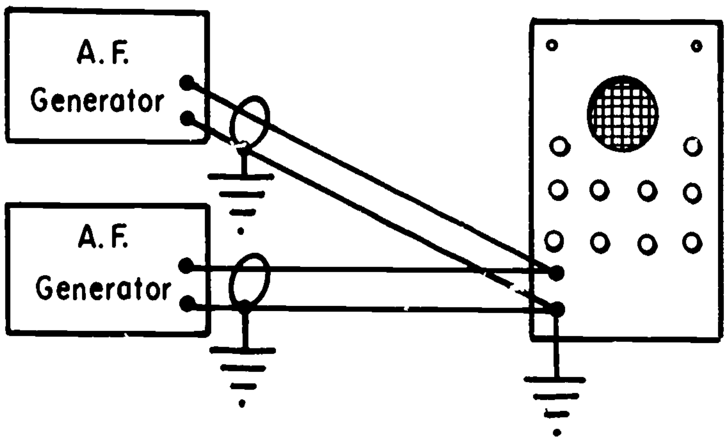
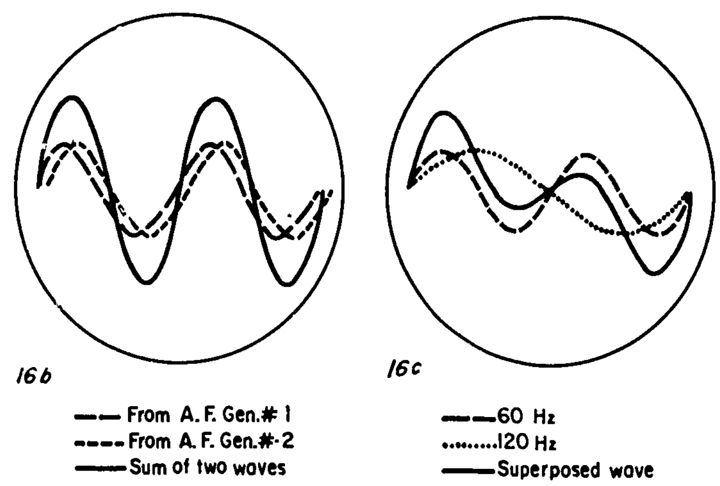


Figure 16a



(Figure 16a), from one A.F. generator and the 60 Hz test signal of the scope, or from two mounted tuning forks playing into a microphone which is connected to the VERT INPUT. This microphone, if connected directly to the VERT INPUT, should have a fairly high output signal such as that obtained from a crystal or ceramic microphone. If the microphone has too low an output signal, it can be connected to an audio amplifier which is in turn connected to the scope through the speaker output terminals.

If a microphone is not available, a small loudspeaker can be used in place of a microphone and will give excellent results if connected as shown in Figure 17.

By setting each A.F. generator to 60 Hz and equal output, it is easy to show how the two signals combine to form one of double the amplitude,

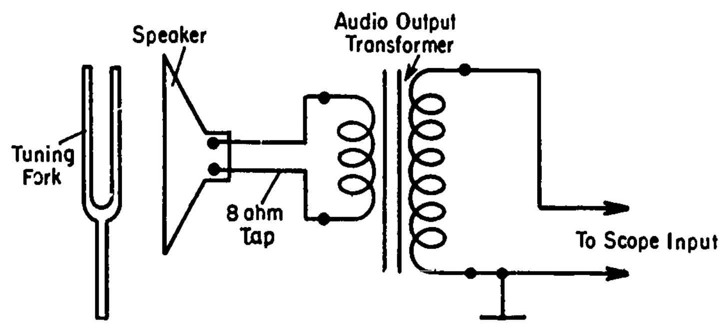


Figure 17

Figure 16b. By setting one A.F. generator to 60 Hz and the other to 120 Hz, the resulting waveform of a fundamental and its first overtone can be shown, Figure 16c. Various other combinations are of course possible. This demonstration is a bit tricky because of the slight drifting of most ordinary A.F. generators. Consequently there may need to be some readjustment of the FINE FREQ, SYNC, or A.F. controls.

Beats—Beats can be shown with the same setup as indicated in Superposition above. One A.F. generator is fixed at one frequency, and the other A.F. generator is then adjusted to a slightly different frequency. As the second A.F. generator frequency is moved away (+ or −) from the fixed frequency of the first, the number of beats will be seen to increase. To insure complete cancellation in the *interfering mode*, the amplitude of the two signals must be equal. If two A.F. generators are used, this can easily be arranged, since each generator can be individually adjusted to a given output.

The beats from two mounted, similar tuning forks (one loaded) can also be clearly seen on the scope if the sound is picked up by a microphone which is connected to the VERT INPUT.

Perhaps the best way to set up demonstrations in sound is to connect the speaker output of an audio amplifier to the VERT INPUT of the scope, as in Figure 18.

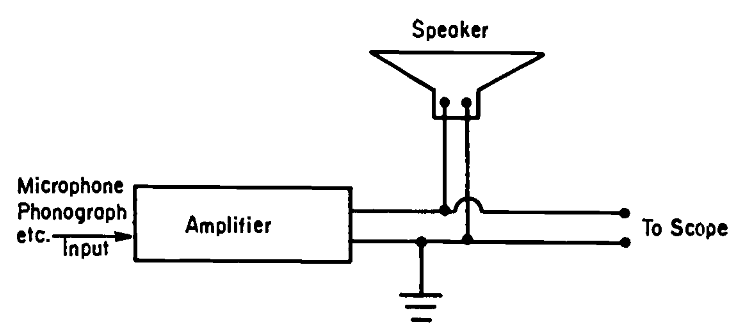


Figure 18

In this arrangement any sound going into the amplifier will be heard in the loudspeaker at the same time the waveform is being viewed on the screen. A.F. generators, a microphone, or other sound sources can be fed into the amplifier and the output heard and viewed. This is particularly effective with beats.

Complex waves—By using a microphone and amplifier, various vowel sounds can be shown to have certain characteristic wave patterns. It can be noted, for instance, that the wave pattern for the *eee* sound contains many more high-frequency components than does the waveform for the *aaah* sound. Correspondingly it can be noted that the

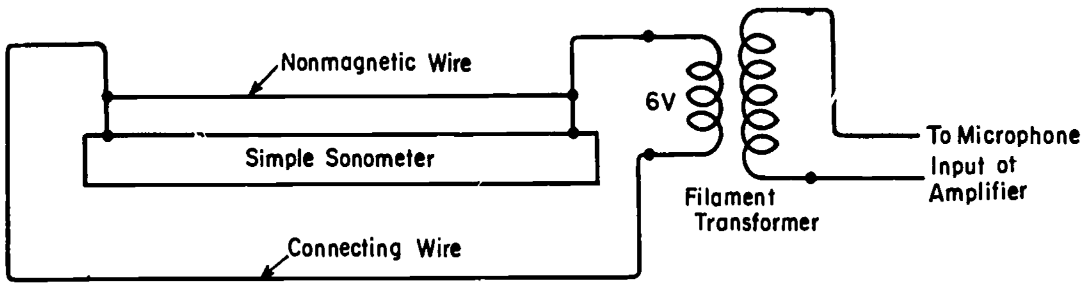


Figure 19

mouth cavity for *eee* is smaller than the mouth cavity for *aaah*. It is also possible to do some interesting analytical work using the Speech Synthesizer Kit which is available from the Bell Telephone Company.

Noise—The random nature of noise shows up excellently when air is blown into the microphone. When this is done near the end of the class period, it is not unusual to have the students whistle, talk loudly, or shuffle and stamp their feet on dismissal.

Sonometers—An interesting experiment can be developed to determine the modes of vibration of a nonmagnetic wire under different conditions of length and tension.[1] The apparatus is set up as shown in Figure 19.

A small filament transformer is connected as a step-up transformer with the secondary connected to the microphone input of an amplifier. The string is set into vibration, and one or more small horseshoe magnets (preferably alnico) are placed at various positions along the string to determine various modes of vibration. By proper adjustment of the frequency controls it is possible to pick out fundamental vibrations and overtones.

Velocity of Sound—A number of methods have been developed for finding the velocity of sound in air. One such method has been completely described in *The Science Teacher*.[2] In this method phase differences are used to determine the wavelength of sound at a known frequency.

Electronic Circuits

Any of the modern electrical or electronic devices which use alternating currents or transient electrical currents are amenable to analysis by using the oscilloscope. The waveforms can be displayed, and the various parameters can be measured or determined by the methods indicated previously. Following are some of the circuits which can be used in the science classroom.

[1] Grubbs, R. C. "Demonstrations in High School Physics." *School Science and Mathematics* 48: 199-201; March 1948.

[2] Amend, John R. "The Velocity of Sound—A Laboratory Research Problem." *The Science Teacher* 31: 20-23; February 1964.

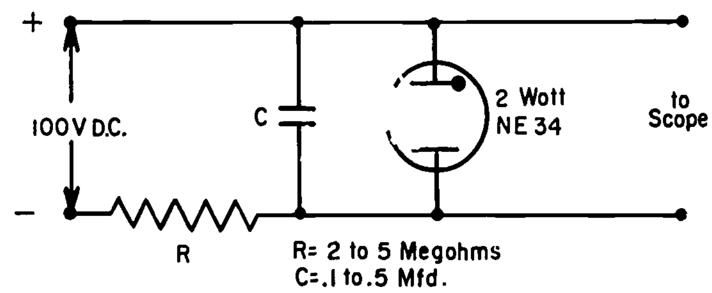


Figure 20a

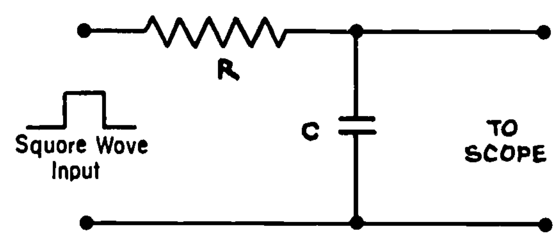


Figure 20b

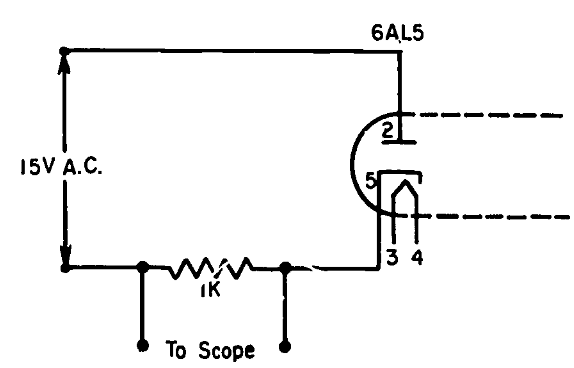


Figure 21

Relaxation oscillator—The circuit shown in Figure 20 can be set up on a breadboard, and sawtooth waves of varying frequencies can be obtained.

The frequency will be determined by the values of capacitance and resistance chosen.

Other sources—The voltage output of various demonstration generators and magnetos can also be shown, thereby showing the conversion of mechanical energy to electrical energy. A St. Louis motor will deliver a very unusual waveform when it is set up as a generator.

Rectification—The rectifying action of diodes can be shown by using the circuit shown in Figure 21.

In this circuit, the oscilloscope should first be connected across the source. The scope should be calibrated for a pattern about 2 inches high and

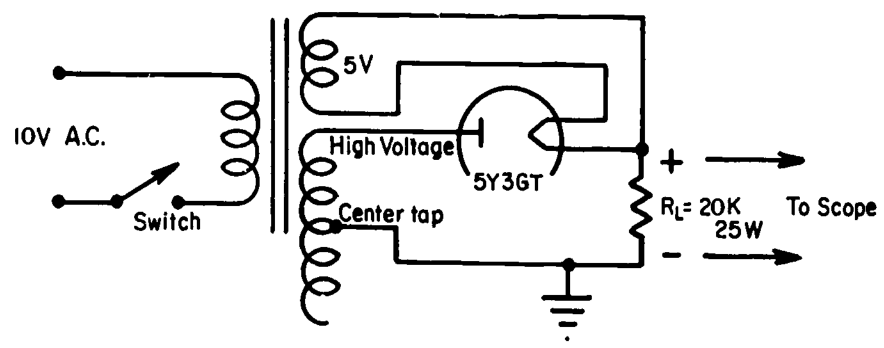


Figure 22

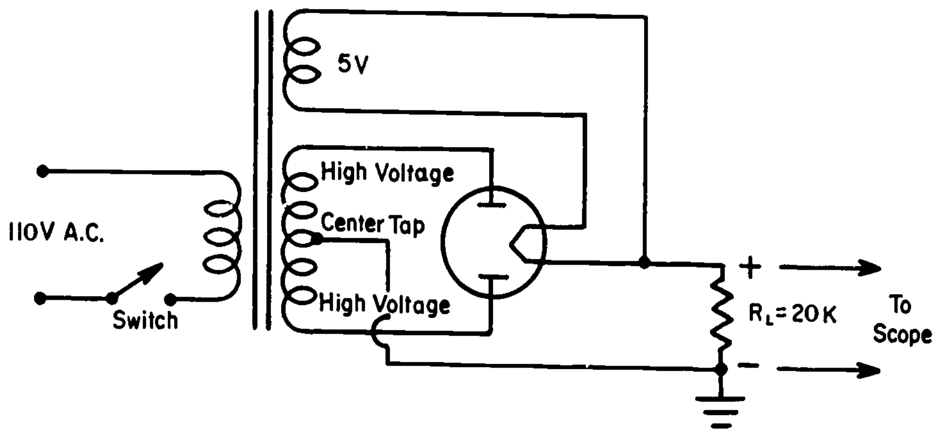


Figure 23

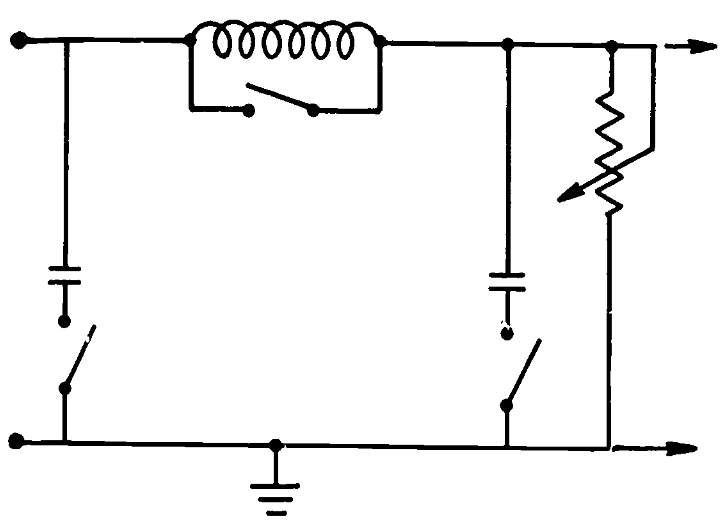


Figure 24

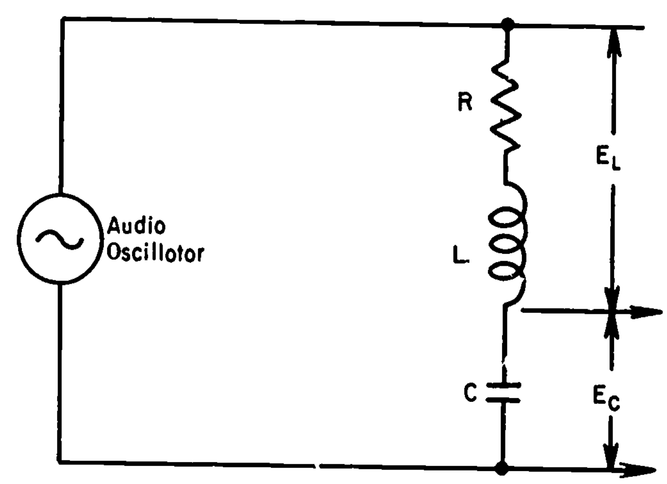


Figure 25a Series Resonant Circuit

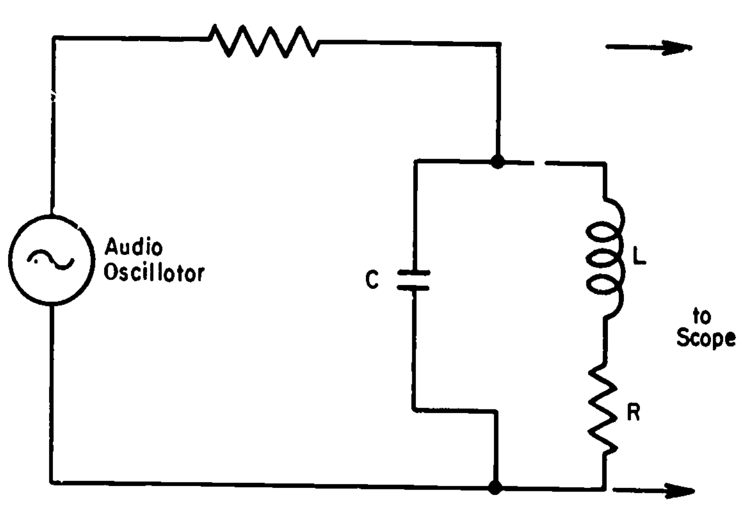


Figure 25b Parallel Resonant Circuit

the sweep frequency adjusted so that three sine waves appear on the screen. The oscilloscope should then be connected across the resistor and the waveform again observed. (A 6J5 tube or a semiconductor diode could also be used to show this action.)

In the circuit shown in Figure 22 a power transformer is connected to a diode rectifier and the output observed across the load resistor.

The circuit is then wired as shown in Figure 23, and again the output is observed across the load resistor.

Figure 24 shows a filter circuit with choke coils and condensers so arranged that the smoothing action of the components can be shown separately or together. Power supply circuits of this sort can often be salvaged from old radio or television sets. **Caution**—When working with high voltages, one must observe proper safety measures. *See section on safety.*

Resonance—The effect of inductance and capacitance on the impedance of an A.C. circuit can be

shown by setting up circuits as shown in Figure 25a and 25b. The values of the circuit components can be calculated for power line or other frequencies. Formulas and information concerning these circuits can be obtained from most texts on electricity. (See also an article by Joseph H. Mack.[3])

SPECIAL USES

There are many other special uses for the oscilloscope. Some of these are listed below:

1. Phase shift of RC circuits.
2. Radio, TV, FM service work (signal training).
3. Square wave testing of high fidelity amplifiers.
4. Percentage modulation measurements in amateur radio transmitters.
5. Modulation envelope of RF signal.
6. Hysteresis.
7. Heartbeat display. (Use a hearing aid as microphone and apply output to VERT INPUT of scope.)—When transient phenomena of a low repetition rate, such as heartbeats, are to be displayed on a CRT screen, it is important to use a CRT screen with a high persistence phosphor.
8. Trigonometry classes. Most scopes can show sine waves easily, and these of course have use in the mathematics class. By use of proper electronic circuitry it is possible to portray other trigonometric functions as well as typical graphs for many second-degree equations.

WAVEFORM PHOTOGRAPHY

Any camera can be used to photograph the waveform on the screen of an oscilloscope. The room should be completely dark, and the scope pilot light should be masked. If the camera is a reflex type with through-the-lens focusing, the camera can be placed at a proper distance and the picture taken as outlined below. If the camera has a view finder (which cannot be used in this instance), focus the camera before loading it with film. This can be done by opening the back and using a ground-glass screen or a piece of waxed paper in place of the film. Once the proper focal distance is determined, picture taking can proceed.

Use the fastest film available. Make sure that the waveform is stationary. Take a series of pictures starting with the largest diaphragm opening and slowest speed (time or bulb if necessary), keeping a record of the exposure settings and the intensity setting. After development the best picture can be selected and the information used for any future photographic work.

Polaroid cameras offer the advantage of immediate development. Focusing can be accomplished as above. One of the more recent models does have a focusing screen adapter. A good picture can usually be obtained from a bright trace using type 44 film at a setting of #13 (or f.8) and an exposure of about four seconds.

TROUBLE-SHOOTING THE OSCILLOSCOPE

If difficulties develop in your oscilloscope the clue to these difficulties is in what happens to the presentation on the CRT screen. By being able to relate any abnormal behavior to the proper circuit, you can often make repairs in a minimum of time.

Trouble-shooting usually consists of two approaches: one that is concerned with gross evidence, such as unlit filaments or components that are or have been overheating, and one that requires a good knowledge of the circuit operation from the viewpoint of electronic theory. The former will be considered here. For those who have sufficient background in circuit theory, the information described below coupled with the oscilloscope instruction book and schematic diagram should make most repairs possible.

Most oscilloscopes that are currently in use in classrooms are vacuum tube devices. To establish a baseline of information concerning your oscilloscope, turn on the instrument and set it up in a normally operating mode with all controls in their normal position. Next turn the instrument off, *unplug the line cord* and remove the oscilloscope from its cabinet. **Caution**—Observe all normal safety precautions to avoid shocks. High voltages are present at several points in the oscilloscope. Be extremely careful in handling the CRT since it is highly evacuated and undue impact on the tube envelope may cause an implosion with the danger of flying glass.

With the oscilloscope removed from its cabinet, remove one of the vacuum tubes and record the tube number and function. Plug in the oscilloscope and turn it on. Note the appearance of the screen and make a record of same. Turn off the oscilloscope, unplug the line cord, replace the vacuum tube and remove one of the other tubes. Repeat the above procedure until a record has been made for all of the tubes.

[3] Mack, Joseph H. "The Oscilloscope in High School Physics Demonstrations." *School Science and Mathematics* 51: 41-58; January 1951.

Since tube failure is one of the most common causes for instrument malfunction, the information thus acquired will be very useful in determining which tube to change in case of trouble.

If difficulties occur which cannot be remedied by changing tubes, unplug the oscilloscope and make a careful inspection of all circuits, looking for burned or broken components, wires, switches, etc. If such a component is found, replace it, plug in and turn on the oscilloscope and watch the component to see whether overheating occurs. If the new part begins to overheat, turn off the oscilloscope and determine the cause of the trouble before using the instrument further.

Some typical failures and their indications are listed below:

1. When a signal is applied to the oscilloscope and only a vertical line appears on the CRT screen. This indicates that there is difficulty in either the sweep circuits or horizontal amplifiers.

2. When a sine wave signal is applied to the oscilloscope and the wavelength is considerably greater on one side of the trace than on the other. This indicates a non-linear sweep and a malfunction in the sweep circuits.

3. When a signal is applied to the oscilloscope and there is no vertical deflection. This indicates a malfunction in the vertical amplifier circuits.

4. No spot on the CRT screen. This could be caused by a bad high-voltage rectifier, by trouble in the low-voltage power supply, or by a faulty CRT.

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